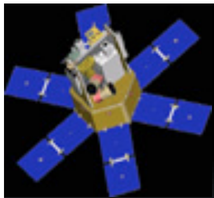

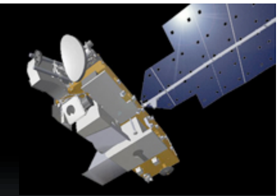

Vertical Profile of the Solar Cycle Induced Variability in Atmospheric OH and the Implications on Ozone

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Background

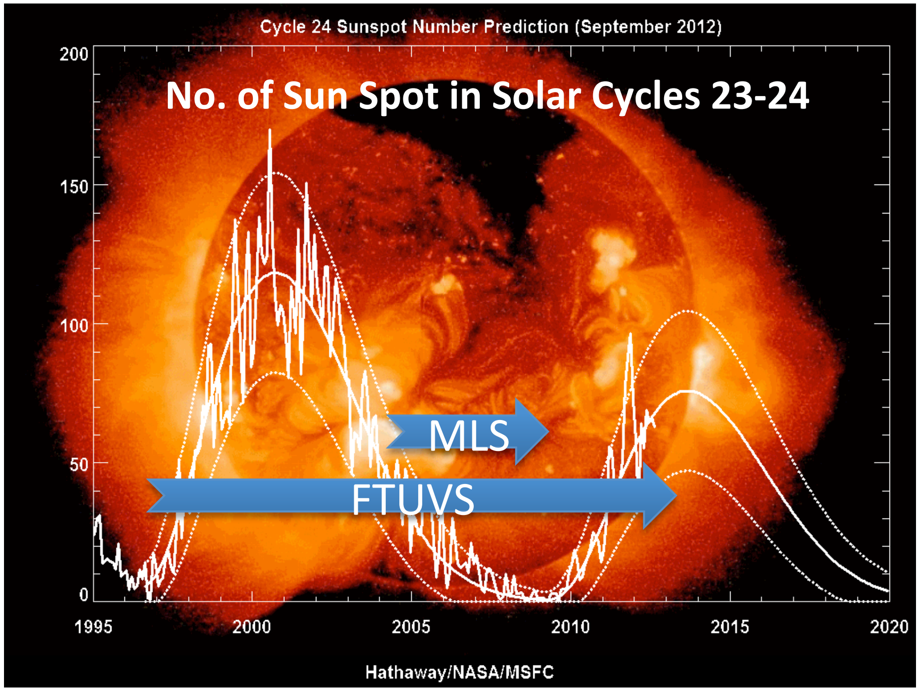
- During the 11-year solar cycle, the total solar irradiance (TSI) varies by only ~0.1%. However, the relative changes in UV is much larger.
- OH, produced through photolysis in UV, is expected to be affected by the solar cycle (SC).

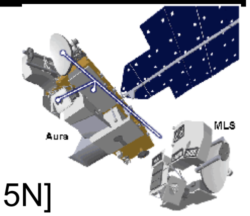
$$H_2O + h\nu \rightarrow OH + H \qquad (Mesosphere)$$

$$O_3 + h\nu \rightarrow O(^1D) + O_2 \qquad (Stratosphere)$$

$$O(^1D) + H_2O \rightarrow 2\ OH$$

- We have extracted the OH SC signal using 15-year ground-based data. The 5-year MLS OH show similar trend.
- The variability in OH and the related HO_x (OH, H, HO_2) chemistry affects the variability in middle atmospheric O_3 (through HO_x catalytic reaction cycles).





Review/Update — Solar Cycle Signal in OH Observations

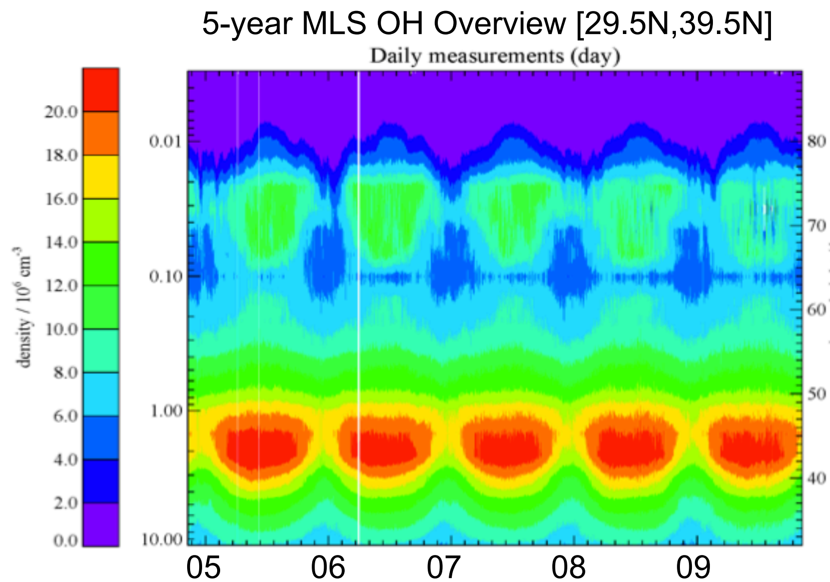
MLS OH Measurements

— 2.5 THz module: 32 – 0.0032 hPa (~90% of total OH)

— Available data: Aug 2004 to Dec 2009

— Future data: 30-day in 2011, 2012, (2013, ……)

[Pickett, 2006, 2008; Wang et al, 2008; Canty et al., 2006]



FTUVS OH Measurements

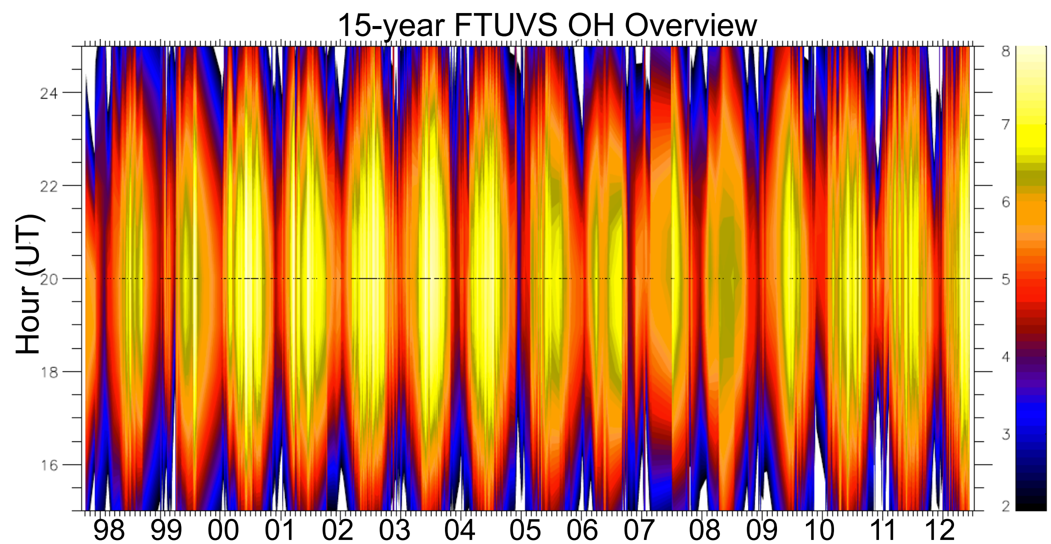
— <u>Fourier Transform Ultra-Violet Spectrometer</u>

— Location: TMF, Wrightwood, CA (34.4°N; ~2.3 km)

— Available data: OH column from 1997 to present

— Required condition: Clear to lightly cloudy sky

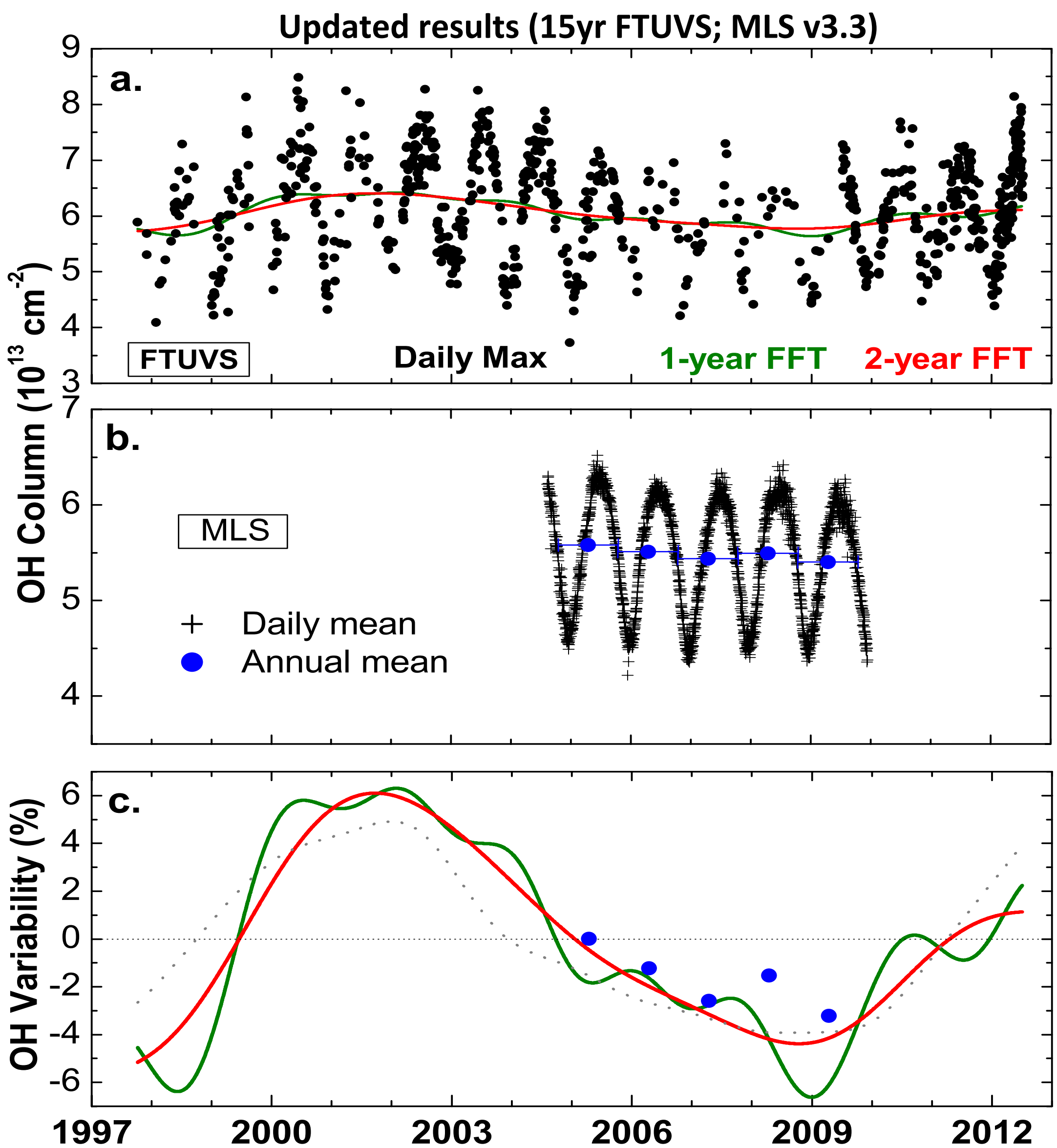
[Cageo et al 2001; Cheung, et al, 2008; Wang et al., 2008]



Major natural OH Variability

- Strong diurnal variation (SZA)
- Strong seasonal variation (SZA, source species)
- Solar cycle signal

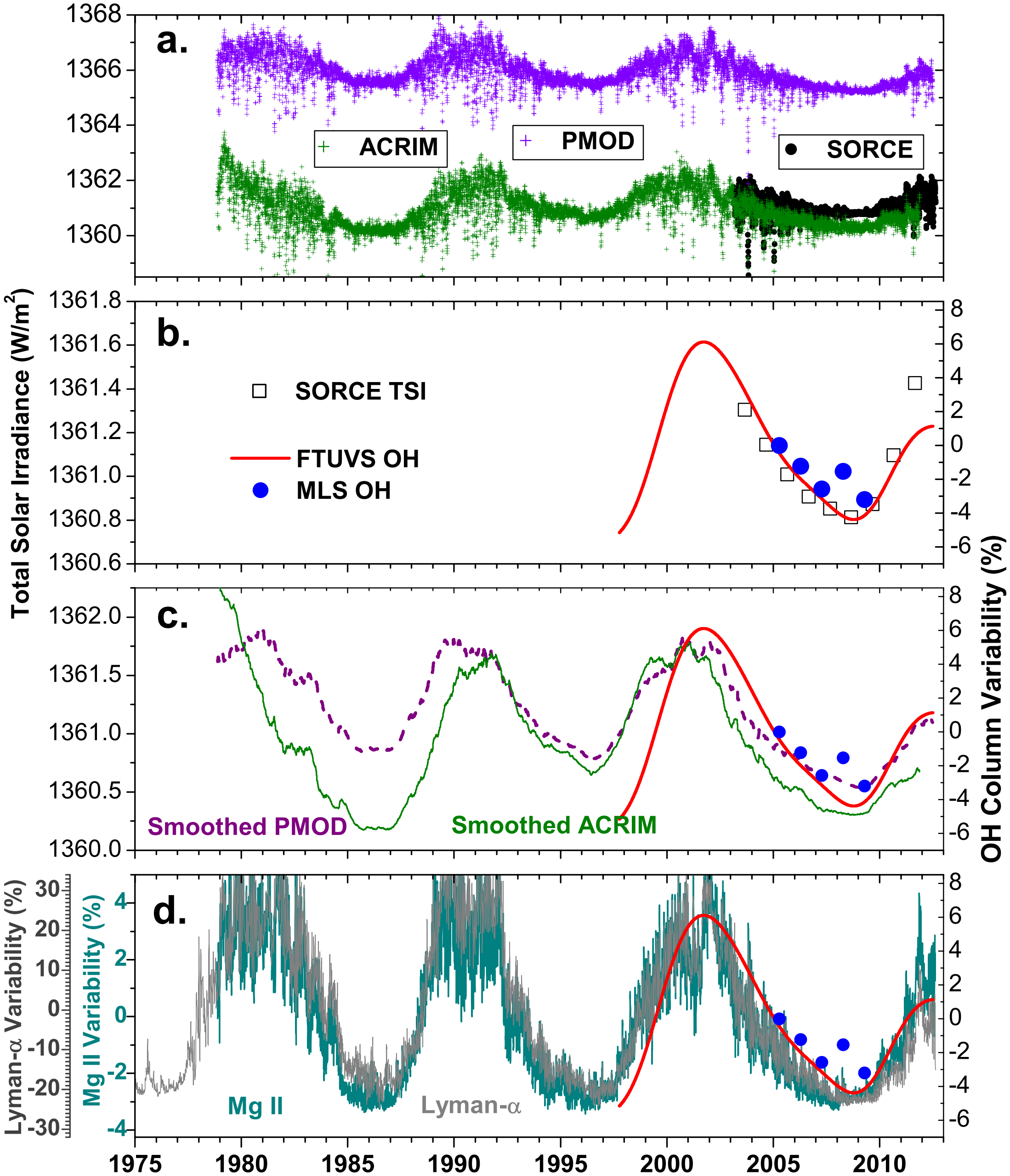
Review/Update — Solar Cycle Signal in OH Observations



~10% in FTUVS

~7% in MLS

[submitted to PNAS]



- The OH long-term variability is:
  ~**10%** in FTUVS OH column
  ~**7%** in MLS OH column

- This OH variability is highly correlated with:
  —TSI
  — Lyman-α (121.5 nm)
  — Mg II index (280 nm)

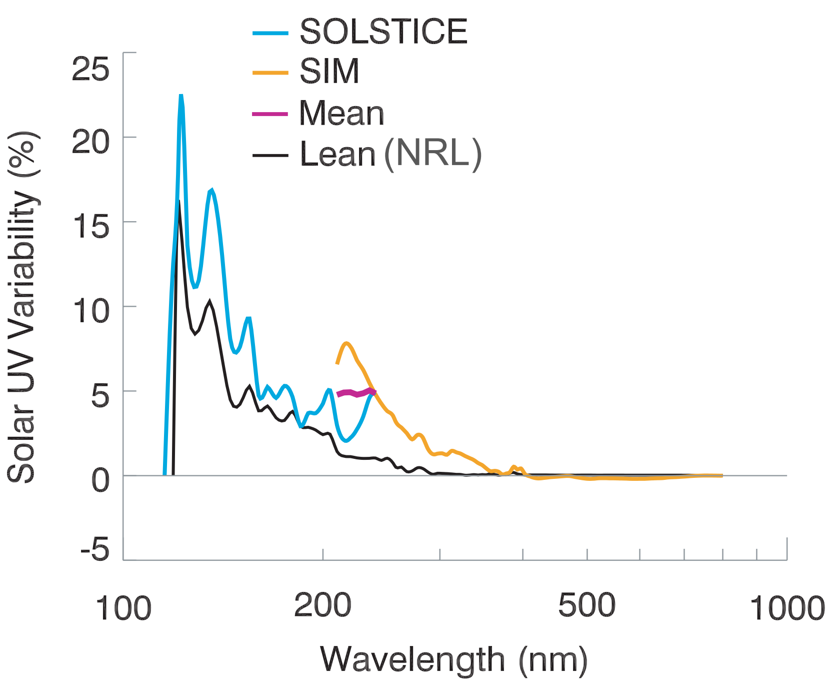
- This observed OH column variability is associated with the solar 11year cycle.

[submitted to PNAS]

Model Simulations

Assuming the middle atmospheric HO_x chemistry is well represented, **solar flux (Solar Spectral Irradiance)** used in models is a crucial factor determining the modeled solar cycle signal in OH.

- NRL SSI based on observations during past solar cycles *[e.g., Lean, 2000]*
  Modeled SSI based on UARS/SOLSTICE UV measurements *[Woods and Rottman, 2002; Marsh et al., 2007; Austin et al., 2008]*
- Recent satellite (SORCE) observations of SSI variability during Solar Cycle 23 appear to be surprisingly larger than that of NRL. *[e.g., Haigh et al., 2010]*

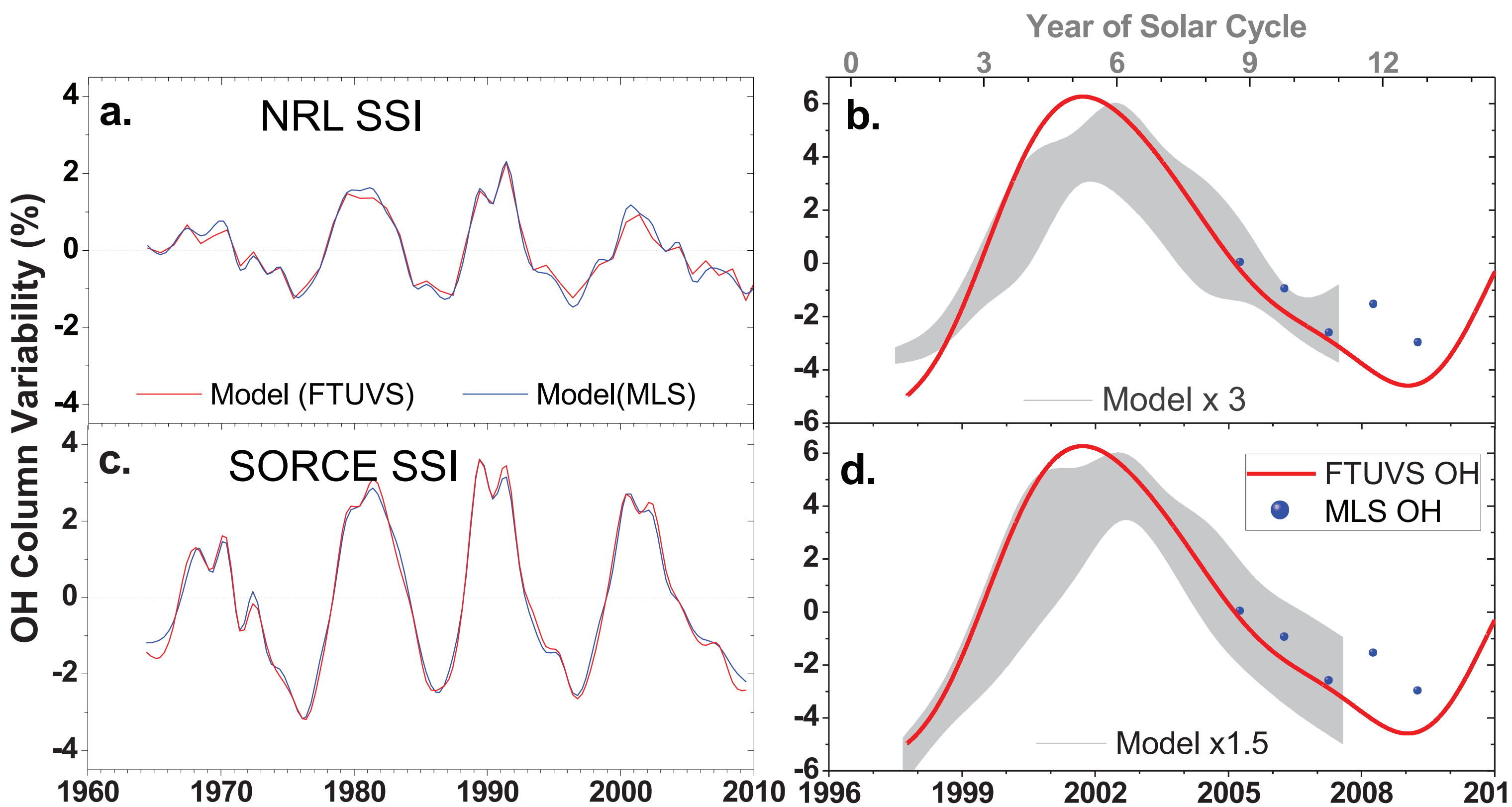


Solar Stellar Irradiance Comparison Experiment (SOLSTICE) — 115 – 300 nm

Spectral Irradiance Monitor (SIM) — 200 – 2700 nm

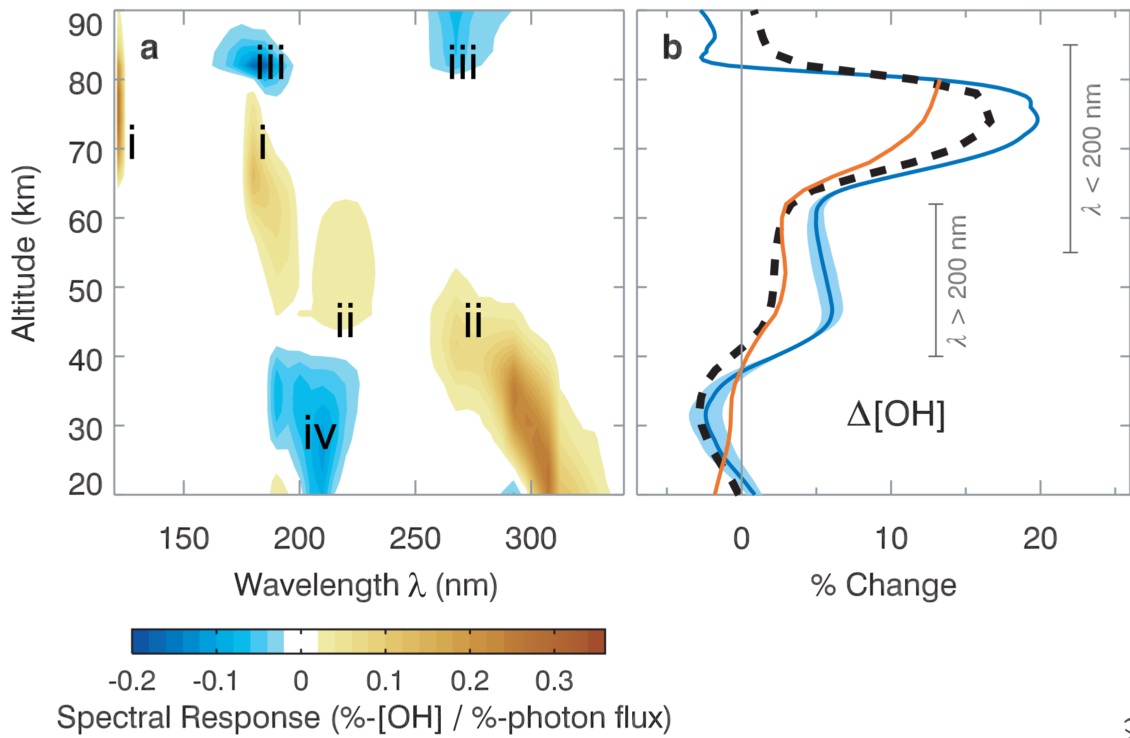
- We use SORCE (SOLSTICE + SIM) SSI variability during 2004 – 2007.
- Using Mg II as proxy, scaling factors are estimated to extend SORCE SSI trend back to solar max in Jan 2002.

OH variability – WACCM vs. Observations

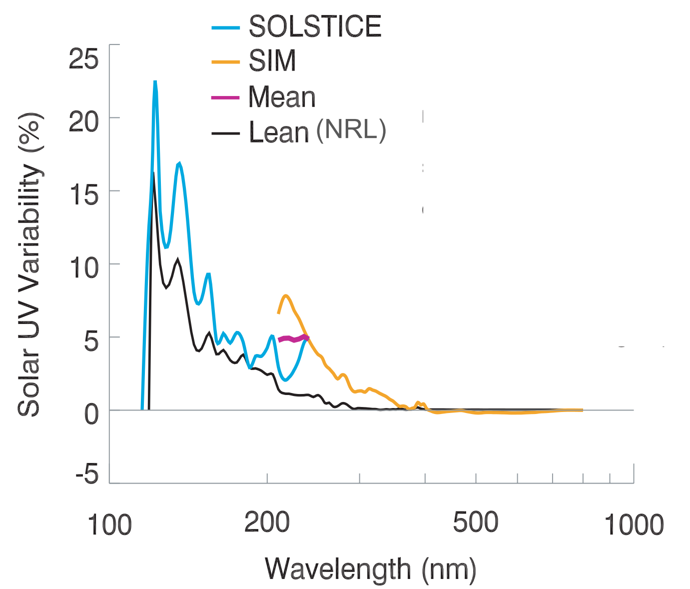


SSI used in WACCM	Modeled OH variability	Difference between model and observations
NRL	~3%	A factor of ~3
SORCE (240 nm cutoff)	~6%	A factor of ~1.5
SORCE (210 nm cutoff)	~7%	A factor of ~1.3

OH variability – 1-D Model



NRL SSI
SORCE SSI
[Canty & Minschwaner, 2002]



i. Enhanced H_2O photolysis (< 200 nm)

ii. $O(^1D) + H_2O \rightarrow OH + O_2$

Enhanced O_3 photolysis (> 200 nm)

iii. $OH + O \rightarrow H + O_3$

Enhanced photolysis of O_2 and O_3

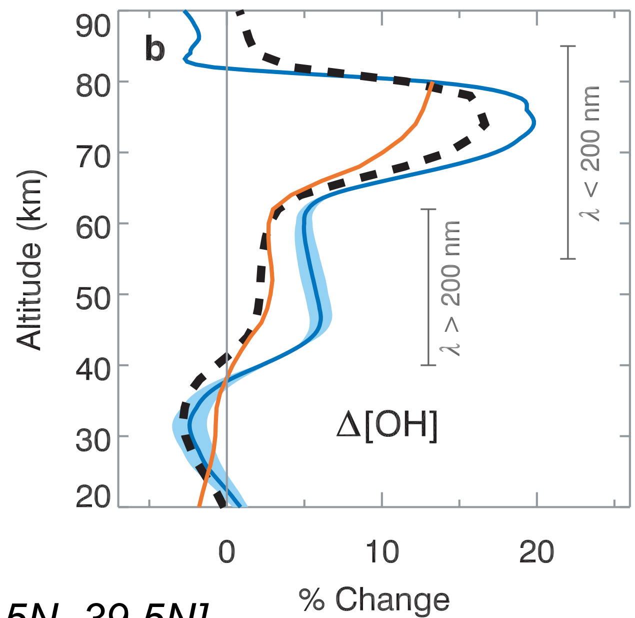
iv. Shielding effect: Enhanced overhead O_3 opacity

OH variability – Vertical Profile

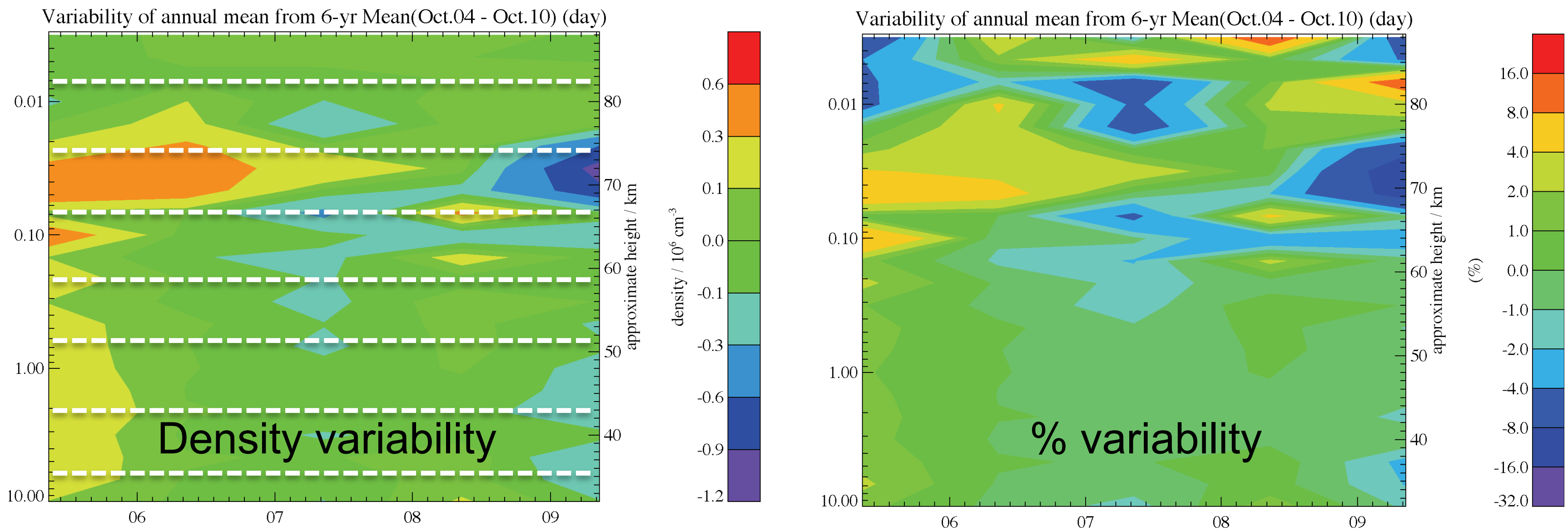
When replacing NRL SSI with SORCE SSI –

- Mesospheric OH SC signal increases by ~15%
  (λ < 200nm)

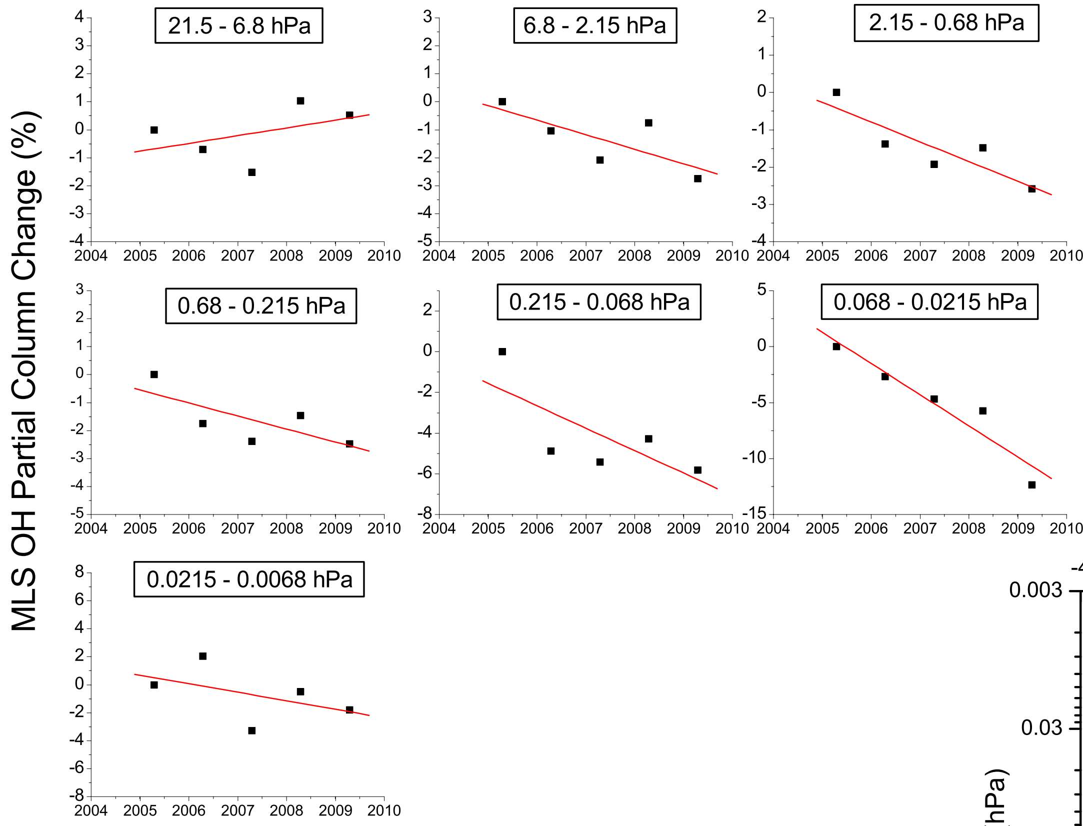
- Upper stratospheric OH SC signal increases by at least a factor of 2
  (λ > 200nm)

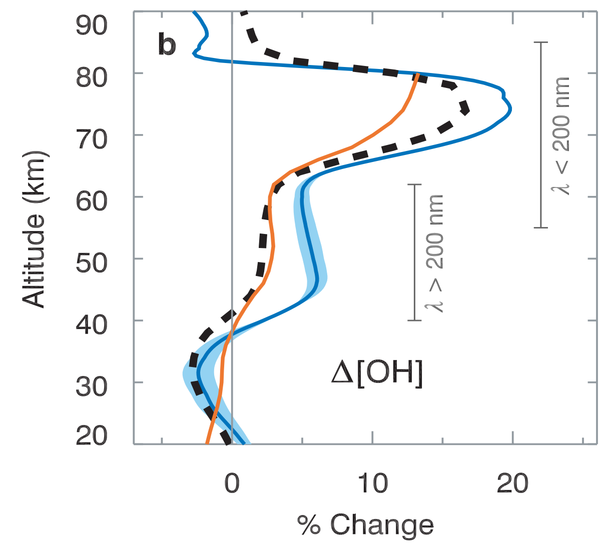


MLS Annual mean OH Variability at [29.5N, 39.5N]

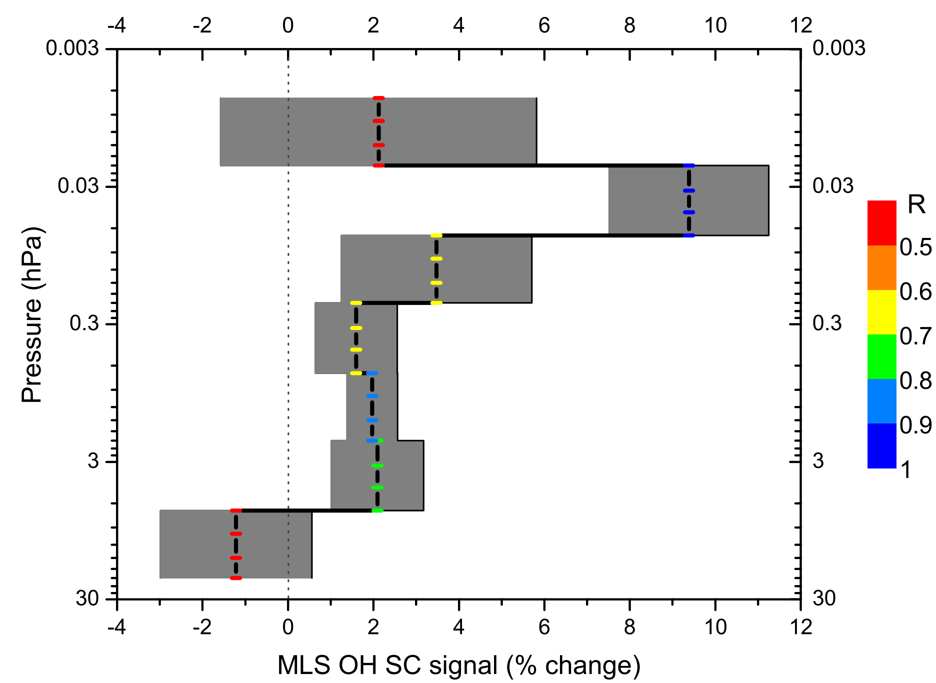


OH variability – Vertical Profile (MLS vs. Model)

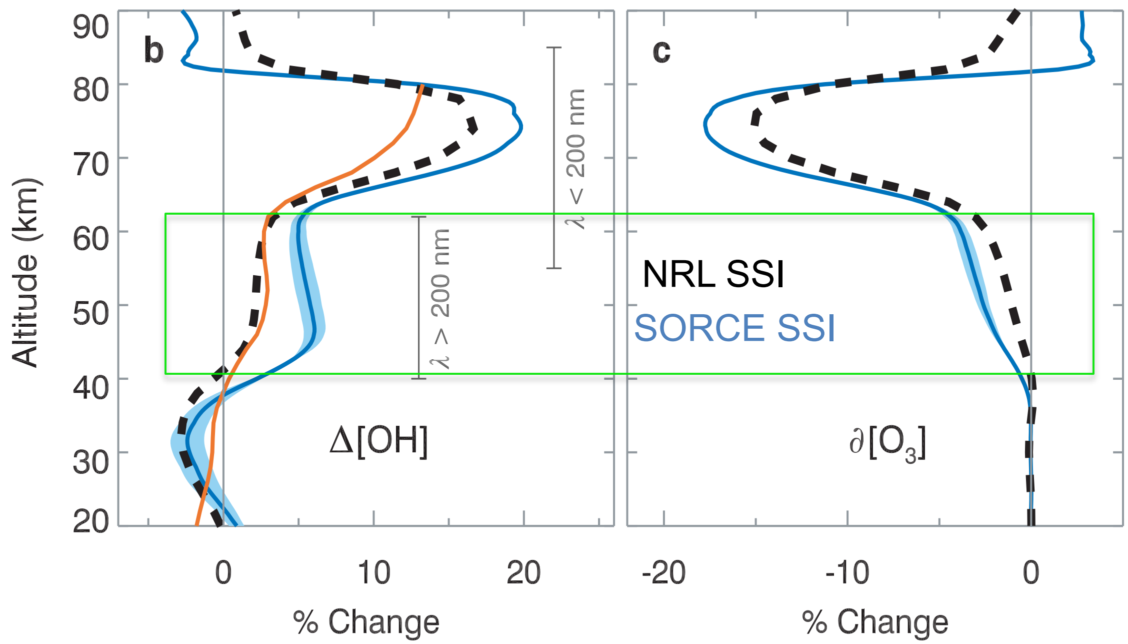




- MLS observations seem to agree better with model using SORCE SSI.
- Current MLS data record is too limited to make solid conclusions.
- More data in the future are required.



OH variability – Implications on O_3



$\Delta[O_3]$ (overall SC signal in O_3) is similar to other studies using same models

[Merkel et al., 2011; Li et al., 2012]

- Direct changes (photolysis)
- Indirect changes (O_3-destroying catalytic HO_x chemistry)
- Other possible indirect changes (e.g., T, circulation)

$\partial[O_3]$ Fix SSI; constrain OH changes (SC max to min) to values in (b)

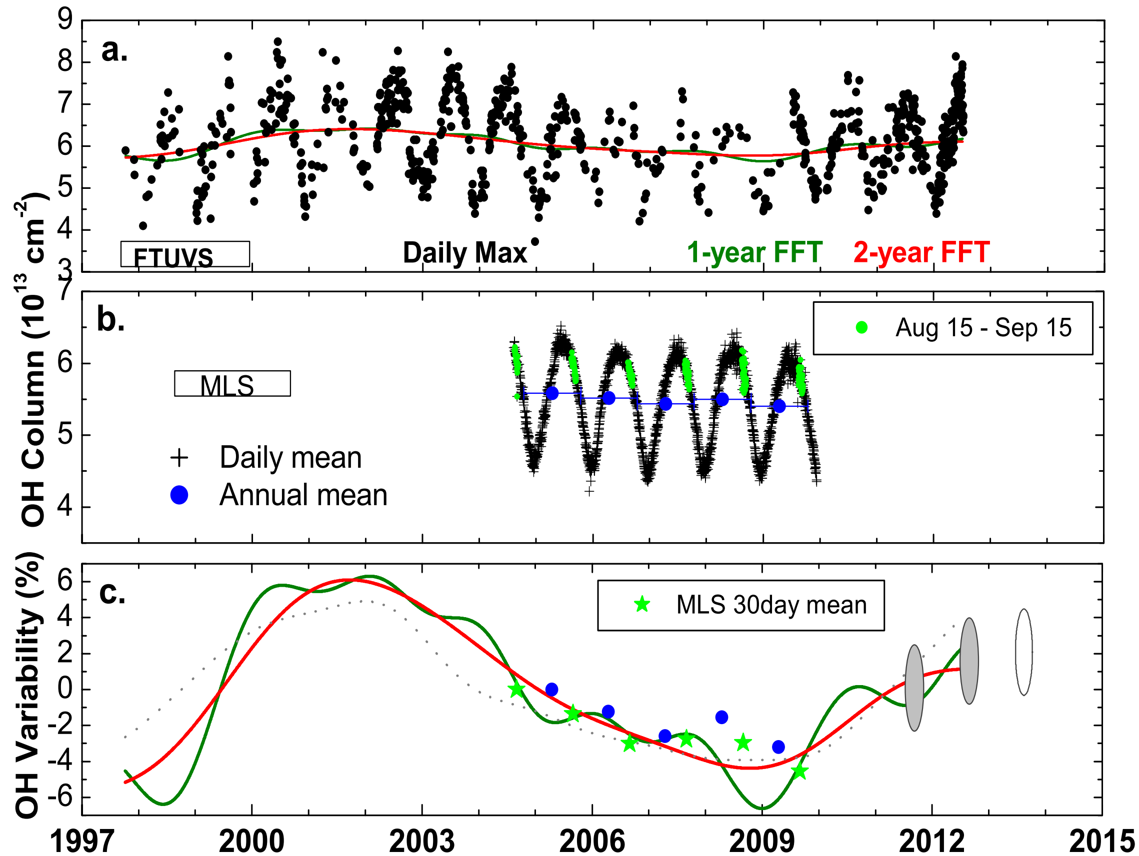
- At 40 – 60 km, using Δ[OH] from SORCE SSI instead of from NRL leads to nearly doubled $\partial[O_3]$ (*similar to what Merkel et al [2011] found in the total $\Delta[O_3]$*)

Continuing OH measurements

• Ground-based OH measurements is continuing.

• MLS OH measurements:
30-day/year in 2011, 2012, ……
(Degradation corrections required)

• These observations through the next solar max will provide extremely valuable evidence for SC signal in HO_x chemistry.



Remaining Questions:

- What are the causes of the discrepancies between SORCE and NRL SSI?
  Are some of the differences due to difference between SC 23 and the previous ones?
- Are our current understanding of the middle atmospheric HO_x-O_3 chemistry complete?

Conclusions

• OH observations (Aura/MLS and TMF/FTUVS) show ~ 7-10% SC signal in OH column. Modeled OH SC signals using NRL SSI and SORCE SSI variability are ~3% and 6-7 %, respectively. ➔ The large discrepancy between NRL and SORCE SSI appears to be one of the dominant uncertainties in atmospheric modeling of SC variability.

• We use 1-D photochemical model to investigate the chemical mechanism of solar cycle signal in OH:
i) H_2O photolysis
ii) O_3 photolysis
iii) shielding effect from overhead O_3

and the implications on O_3 ➔ At 40 – 60 km, OH and its SC variability may play a dominant role in the decadal variation in O_3 (through HO_x reaction cycles).

Continuing measurements of OH, along with O_3 and solar SSI, through the next solar cycle will be extremely valuable to answer the remaining questions.